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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 308

PRESSURE DISTRIBUTION ON A SLOTTED R.A.F. 31 AIRFOIL
IN THE VARIABLE DENSITY WIND TUNNEL

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Memorial Aeronautical
Laboratory

Washington
June, 1929



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Summary

Measurements were made in the variable density wind tunnel of the National Advisory Committee for Aeronautics to determine the pressure distribution over one section of a R.A.F. 31 airfoil with a leading edge slot fully open. To provide data for the study of scale effect on this type of airfoil, the tests were conducted with air densities of approximately one and twenty atmospheres.

Diagrams representing the pressure distribution over the surfaces at several angles of attack, as obtained from the tests at both the high and the low scale, are given together so that the scale effect on pressure distribution may be studied. Curves representing the normal force coefficient and the center of pressure at both the high and the low scale are plotted against angle of attack. Vectors representing the air forces on the auxiliary airfoil in the open position were deduced from the high scale tests and plotted in order to provide data for designing a mechanism for controlling the slot. A rule for estimating the air load on the auxiliary airfoil for stress calculations is also deduced.

Introduction

The slotted wing is not a new development and extensive model tests have been carried out in England on this form of airfoil. However, the full scale investigation of slotted airfoils has been limited to a few flight tests. In view of the small size of the slot and auxiliary airfoil used in tests of slotted wing models and in view of the obvious importance of viscosity effects within the slots, it has been generally conceded that a large scale effect on such wings might be expected. An investigation of scale effect on slotted airfoils can be carried out to advantage in the variable density wind tunnel because tests at both a low and a high scale can be made under similar conditions and the results of the two compared directly. An extensive program of force tests on slotted wings in the variable density wind tunnel has been formulated, but cannot be carried out for some time. In the meantime, the development of the automatic leading edge slot for lateral control has increased the general interest in slotted airfoils and the need for full scale test results.

The investigation of the distribution of pressure over one slotted airfoil, covered in this report, may be considered as part of this more extensive program. It is hoped that this investigation, which could be made earlier than the more extensive one, will supply some much needed data on the characteristics of a slotted wing at a full scale Reynolds Number and also

give some indication as to the effect of the dynamic scale upon the maximum lift coefficient. Furthermore, the results of the present investigation provide data for strength calculations on both the main and auxiliary airfoil which are not ordinarily obtained from force tests.

Since only one slotted combination was to be tested at this time, it was desirable to choose one which would have good characteristics. The R.A.F. 31 airfoil was chosen because extensive tests had been carried out on it in other wind tunnels. The British Aeronautical Research Committee had determined the location of the auxiliary airfoil with respect to the main airfoil which gave the highest maximum lift coefficient (Reference 2). This airfoil was developed by the staff of the British Aeronautical Research Committee working in conjunction with Messrs. Handley Page, Ltd., in an effort to produce a moderately thick airfoil which would have very good high-speed characteristics with the slot closed and a high maximum lift with the slot open.

Tests and Apparatus

Pressures were measured at fifteen points along one section on the surface of each airfoil at angles of attack ranging from -14° to $+34^{\circ}$ by three-degree increments. These tests were made with air densities of about one atmosphere and about twenty atmospheres, thus giving results for comparison with the results of other tunnel tests and also results at approximately full

scale Reynolds Number.

A statement of the principles upon which the variable density tunnel operates to give full scale results, and a description of the tunnel, may be found in Reference 1. However, the description there given is of the old tunnel. The rebuilt tunnel is of the open throat type, as shown in the diagrammatic cross section of Figure 1.

The model and mounting are shown in Figures 2 and 3. The ordinates of the model R.A.F. 31 airfoil as taken from Reference 2 are given in Table I. The model was constructed to a scale such that the chord would have been 10 in. with the slot closed. The span of the model was 6 ft., so that it passed across the open test section and well into the dead air space on each side of the 5-foot jet. All of the pressure orifices were located on the center line of the tunnel. Only fifteen were built into each airfoil because the photomanometer which was available for these tests had only fifteen pressure units. The main airfoil was made of mahogany into which pressure tubes were laid. In order to save expense, only the central portion of the auxiliary airfoil was made of metal. This was slotted to receive the pressure tubes and afterward filled with solder and scraped to give a smooth surface.

For the one-atmosphere tests the orifices were connected with the tubes of a manually operated multiple alcohol manometer. A record of the deflection of the meniscus in each tube

was made by exposing a sheet of photostat paper placed against the tubes. All pressures were measured with respect to the pressure in the dead air space surrounding the jet. The ratio of the deflection in each tube to the deflection in a tube connected with a calibrated static pressure orifice in the return passage of the tunnel was multiplied by the calibration factor to obtain the ratio of the local pressure to the dynamic pressure for plotting.

For the twenty-atmosphere tests it was necessary to use an automatic photo-recording manometer. A description of a similar instrument will be found in Reference 5. An orifice was connected with each unit of the manometer and the pressures on all orifices were recorded simultaneously for a period of about five seconds at each angle of attack while the dynamic pressure was measured independently by means of an alcohol manometer connected to the static plate. For several reasons the results obtained from the twenty-atmosphere tests are not as accurate as those from the one-atmosphere tests. The width of the lines on the manometer records was of the order of that which would be produced by pressure pulsations of ± 10 per cent of the dynamic pressure. The pressure readings were also subject to errors in the calibration of the manometer units. The mechanism for supporting the airfoil and changing the angle of attack, shown in Figure 2, was not sufficiently rigid to maintain its calibration accurately under the large forces encountered during a

twenty-atmosphere run.

R e s u l t s

Figures 4 to 9 represent the pressures on the surface of the airfoil plotted against the projected distance along the chord for several different angles of attack. In each figure the results of both the one- and the twenty-atmosphere tests are given together for comparison. All of the results are for the condition of the slot fully open, that is, with the auxiliary airfoil mounted in the position given in Reference 2 as that which produces maximum lift for the system.

In Figure 10, normal force coefficients for the complete slotted airfoil are plotted against the angle of attack, no correction being made for aspect ratio or tunnel wall effect. Curves representing the coefficient of force on the auxiliary airfoil normal to the chord of the main airfoil are also given. In all cases the coefficients are based on the area of the wing with the slot closed.

Pressure distribution diagrams similar to those of Figures 4 to 9, were integrated to obtain the pitching moment coefficient about a point on the chord line. This divided by the coefficient of normal force gives approximately the center of pressure. The center of pressure coefficients so obtained are plotted against angle of attack in Figure 11. As before, the results of both the one- and twenty-atmosphere tests are given together.

To provide data for strength calculations on the auxiliary airfoil and its support, vectors representing the forces in magnitude, direction and position acting on the auxiliary airfoil in the fully open position are drawn in Figure 12.

D i s c u s s i o n

Scale Effect.— This investigation is probably the first attempt to measure the characteristics of a slotted wing under similar conditions at both a low and a high Reynolds Number. This phase of the investigation is of particular importance because the results may assist in the interpretation of the results of many other low scale tests.

The scale effect may be studied by referring to the pressure distribution diagrams of Figures 4 to 9, and the diagrams of normal force coefficient in Figure 10, where curves representing the results of both the low and the high scale tests are given together. The diagrams of Figures 4 and 5, which correspond approximately to zero lift and high speed, are of little interest in case the slot is automatically closed under these conditions. Between the angles of attack of 10° (Fig. 6), where the slot would normally open, and 16° (Fig. 7), the bubble point of the high scale tests, the lift on the auxiliary airfoil and the negative pressures over the upper surface of the main airfoil are greater for the high scale tests. Above 16° the curves of normal force at the high scale on both the

main and auxiliary airfoils flatten out; whereas, for the low scale tests, the normal force continues to increase until an angle of attack of about 24° is reached. At higher angles of attack the low scale normal force falls off on both the main and auxiliary airfoils, but the high scale normal force increases on the auxiliary airfoil up to an angle of attack of 31° (Fig. 9).

A study of the pressure distribution diagrams indicates that the scale effect results principally from changes in the flow which modify the pressures over the upper surfaces of the airfoils. The effect of scale is also to cause the critical points of the flow to occur at different angles of attack.

Airfoil Characteristics.— The curves of normal force coefficient in Figure 10 indicate approximately the form of lift coefficient curves. However, it must be remembered that these curves represent forces on only the center portion of a wing while force tests give an average loading over the whole wing. The lift curve of an elliptical wing where all sections work at the same angle of attack probably would approach this shape more closely than that of a wing of rectangular plan form. In any event, it is evident that at full scale there will be no sudden break in the lift curve immediately following the burble point so that the advantages of a flat-top lift curve, as outlined in Reference 3, may be realized. At the same time, the maximum lift coefficient is very high as compared with other good high-speed airfoils which do not have abrupt changes in

lift near the burble point.

Referring to Figure 11, it is seen that the movement of the center of pressure is not excessive. At high angles of attack, up to 32° , the center of pressure remains well forward instead of receding as it would with the same airfoil without the slot.

Forces on the Auxiliary Airfoil.— An examination of the results of the twenty-atmosphere tests indicates that the auxiliary airfoil itself burbles when the wing reaches an angle of attack of approximately 31° . The forces on it are a maximum just before reaching this burble point, but between 16° , where the main airfoil begins to burble, and 31° , where the auxiliary airfoil begins to burble, neither the air force nor the center of pressure on the auxiliary airfoil changes greatly. It is, therefore, suggested that the air forces at 16° angle of attack, the burble point of the system, be used as a basis for stress calculations on the auxiliary airfoil and its supporting mechanism. It is unlikely that air speeds sufficiently high to produce larger forces would ever be obtained at higher angles of attack. This angle also corresponds roughly with the most forward position of the center of pressure of the system, 22 per cent of the chord behind the leading edge of the wing with the slot closed. Referring to Figure 12, the air force on the auxiliary airfoil at this angle of attack is nearly normal to the chord of the auxiliary airfoil, passing through a point 43 per cent of the chord behind the leading edge. The magnitude

of the force corresponds to a coefficient of 2.35 based on the projected area of the auxiliary airfoil on its chord. This value is 1.5 times the maximum normal force coefficient of the system as a whole. To sum up, these results indicate that the auxiliary airfoil and its support should be designed to withstand an air load acting normal to its chord through a point 43 per cent of its chord behind its leading edge. This load, expressed in pounds per square feet of area of the auxiliary airfoil, may be found by multiplying the normal wing loading of the airplane with the slot closed by the high incidence load factor and by the factor 1.5.

The vector diagram of Figure 12 indicates that there should be no difficulty with the design of a suitable mechanism for automatically opening the slot at angles of attack near the burble point. A complete study of this subject would, of course, require an investigation of the forces acting on the auxiliary airfoil when mounted in several positions between fully open and fully closed. Pressure distribution measurements taken on an auxiliary airfoil with the slot closed will be found in Reference 4. The results there given show that the forces on the airfoil in the closed position depend to a considerable extent on how the closed slot is vented. It should usually be vented at the top because, as a rule, there is a tendency for the slot to open too early.

The diagram here given indicates that it would be possible

to design an automatic opening and closing mechanism which could be interconnected with the aileron control to close the slot with the up-moving aileron without producing very large loads on the aileron control.

C o n c l u s i o n s

The full scale maximum lift is somewhat lower than the maximum lift indicated by low scale tunnel tests on the slotted R.A.F. 31 airfoil, but the lift does not drop off so suddenly above the burble point.

The full scale maximum lift of the slotted R.A.F. 31 airfoil is high for a moderately thick airfoil having good high-speed characteristics and no abrupt break in lift above the burble point.

The air load on the auxiliary airfoil may be estimated for purposes of stress calculation by assuming a load to act normal to its chord through a point 43 per cent of its chord behind its leading edge. This load per unit area of the auxiliary airfoil may be found by multiplying the normal wing loading of the airplane with the slot closed by the high incidence load factor and by the factor 1.5.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., March 11, 1929.

TABLE I.

Dimensions of Auxiliary and Main Airfoils

All dimensions are given as ratios of the dimension to the chord of the system with slot closed

| Auxiliary Airfoil | | | Main Airfoil | | |
|----------------------------|---------------|---------------|----------------------------|---------------|---------------|
| Distance from leading edge | Upper surface | Lower surface | Distance from leading edge | Upper surface | Lower surface |
| 0 | .0085 | .0085 | 0 | .052 | .052 |
| .0025 | .0175 | .0006 | .0125 | .078 | .046 |
| .005 | .0201 | .0005 | .025 | .088 | .041 |
| .010 | .0230 | .0045 | .05 | .102 | .033 |
| .015 | .0247 | .0074 | .10 | .1185 | .0215 |
| .02 | .0256 | .0095 | .15 | .127 | .013 |
| .03 | .0268 | .0125 | .20 | .131 | .008 |
| .04 | .0266 | .0140 | .25 | .133 | .0045 |
| .05 | .0258 | .0146 | .30 | .132 | .002 |
| .06 | .0244 | .0146 | .35 | .129 | .001 |
| .07 | .0223 | .0140 | .40 | .1255 | 0 |
| .08 | .0198 | .0127 | .45 | .1205 | 0 |
| .09 | .0170 | .0112 | .50 | .1135 | .0005 |
| .10 | .0140 | .0092 | .55 | .106 | .0015 |
| .11 | .0107 | .0069 | .60 | .097 | .0025 |
| .12 | .0072 | .0044 | .65 | .0875 | .0035 |
| .13 | .0038 | .0015 | .70 | .077 | .0035 |
| .1358 | .0003 | .0003 | .75 | .065 | .0035 |
| | | | .80 | .053 | .003 |
| | | | .85 | .040 | .002 |
| | | | .90 | .0275 | .001 |
| | | | .95 | .015 | .0005 |
| | | | .993 | .0015 | .0015 |

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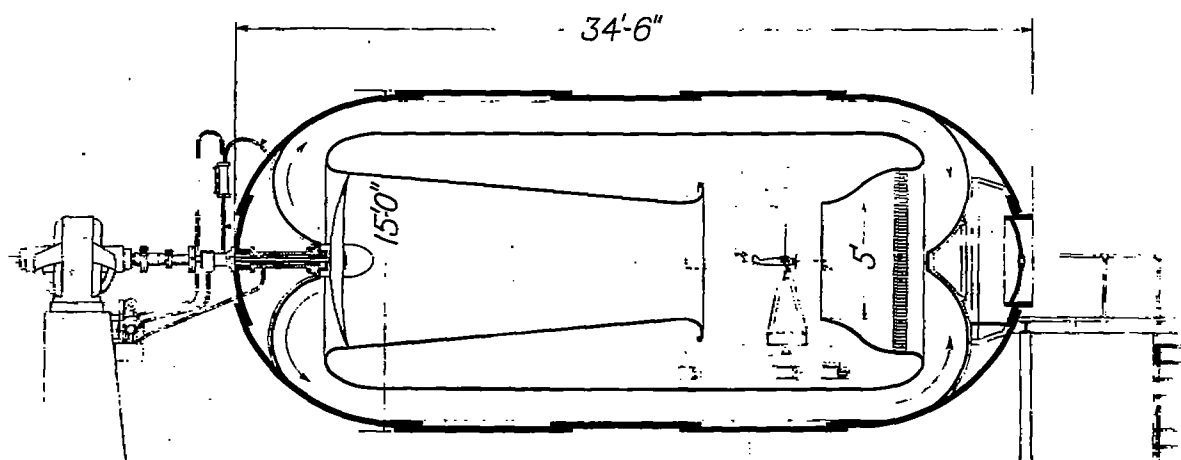


Fig.1 Diagrammatic section of the redesigned Variable Density Wind Tunnel.

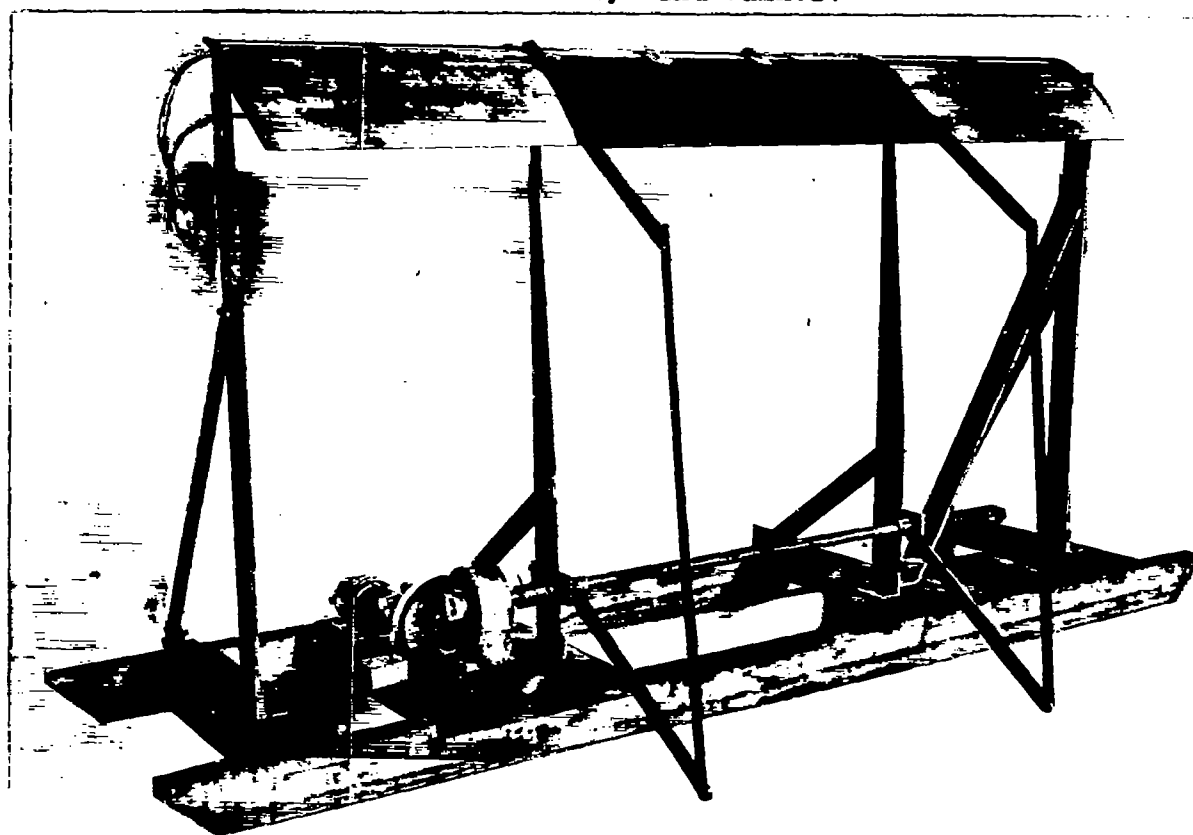


Fig.2 Model slotted R.A.F. 31 airfoil and mounting for pressure distribution tests.

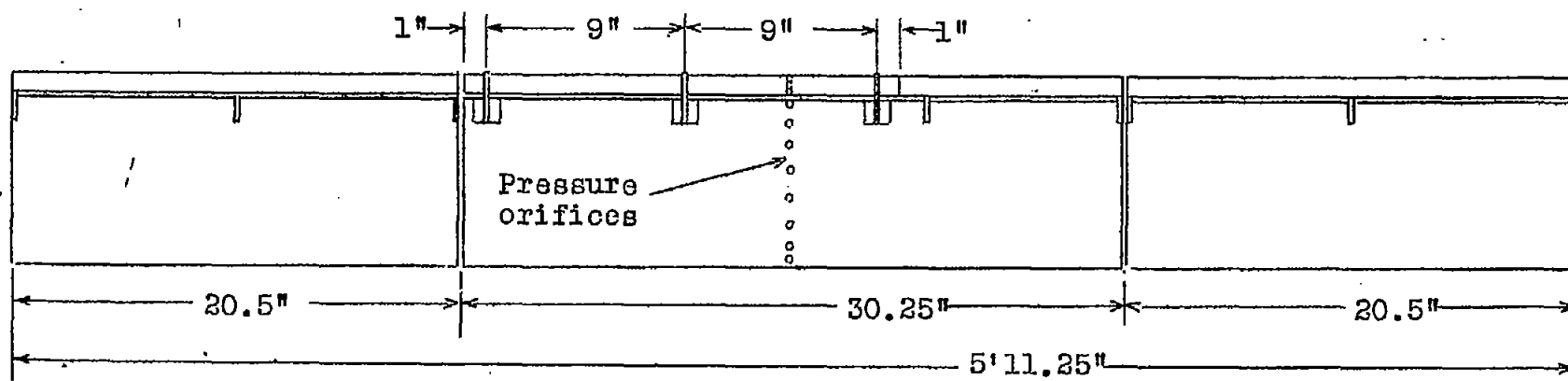
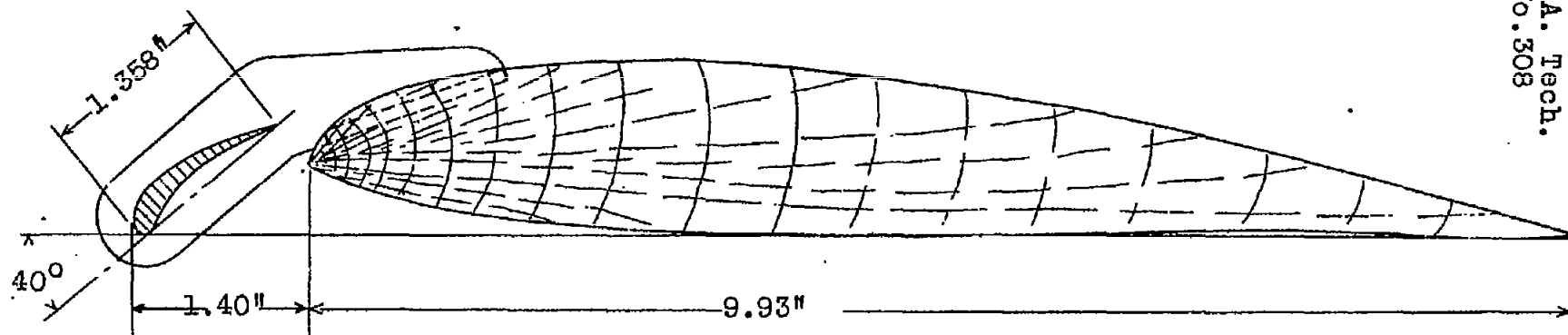
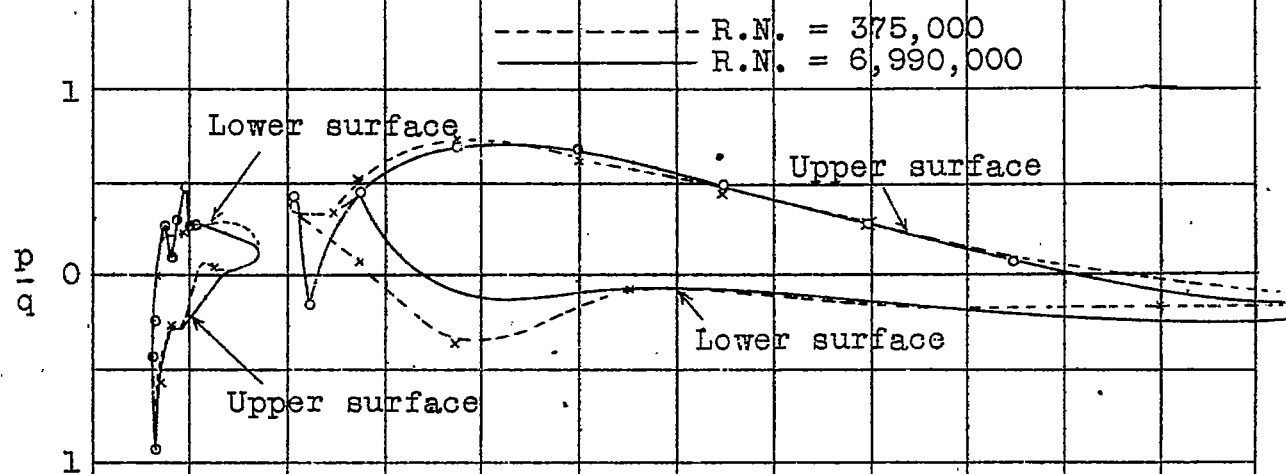
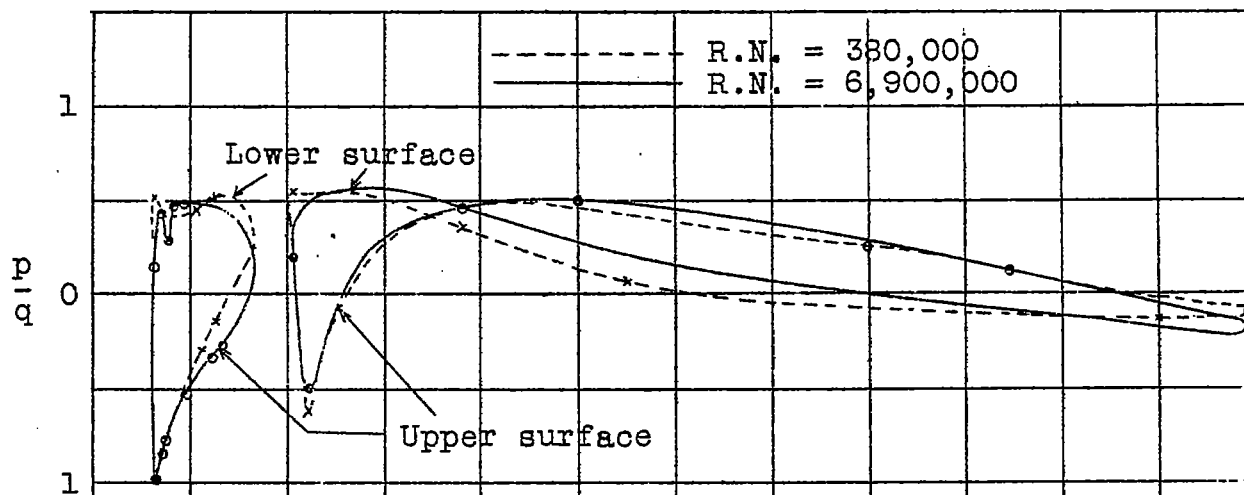
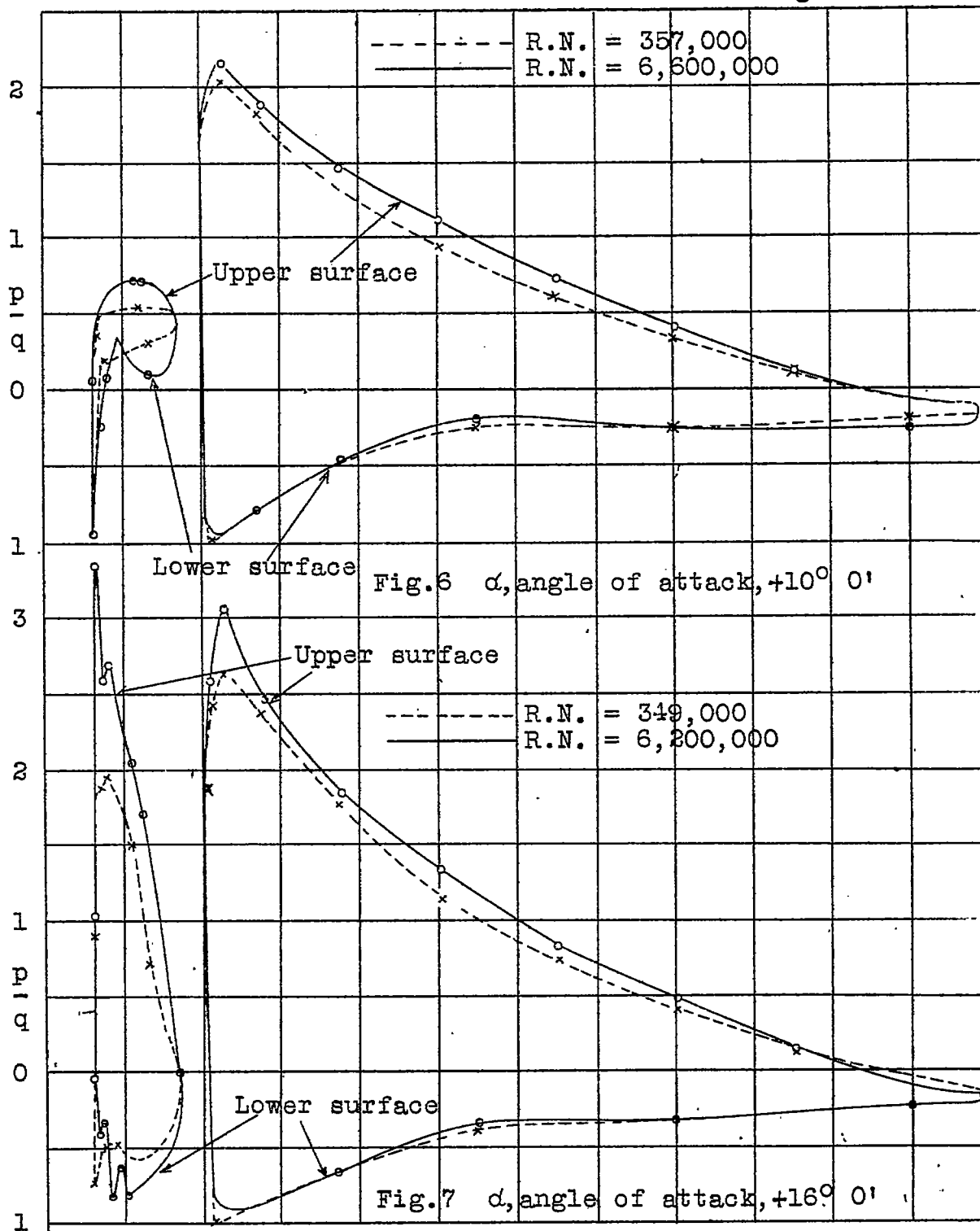


Fig. 3 R.A.F. 31 airfoil section with Handley Page slot showing location of auxiliary airfoil.



Pressure distribution diagram. Slotted R.A.F. 31 airfoil.
Slot fully open.



Pressure distribution diagram. Slotted R.A.F. 31 airfoil.
Slot fully open.

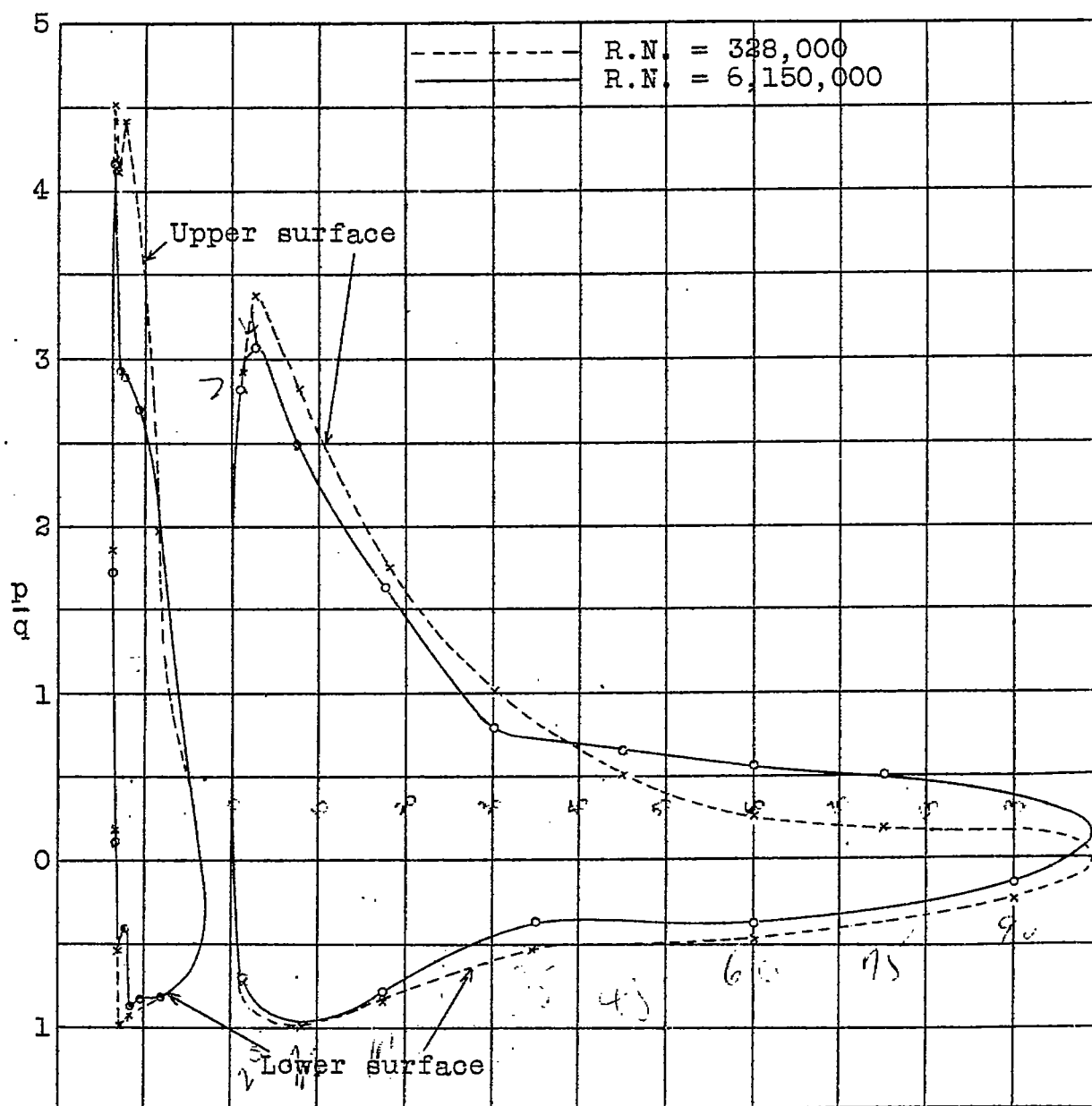
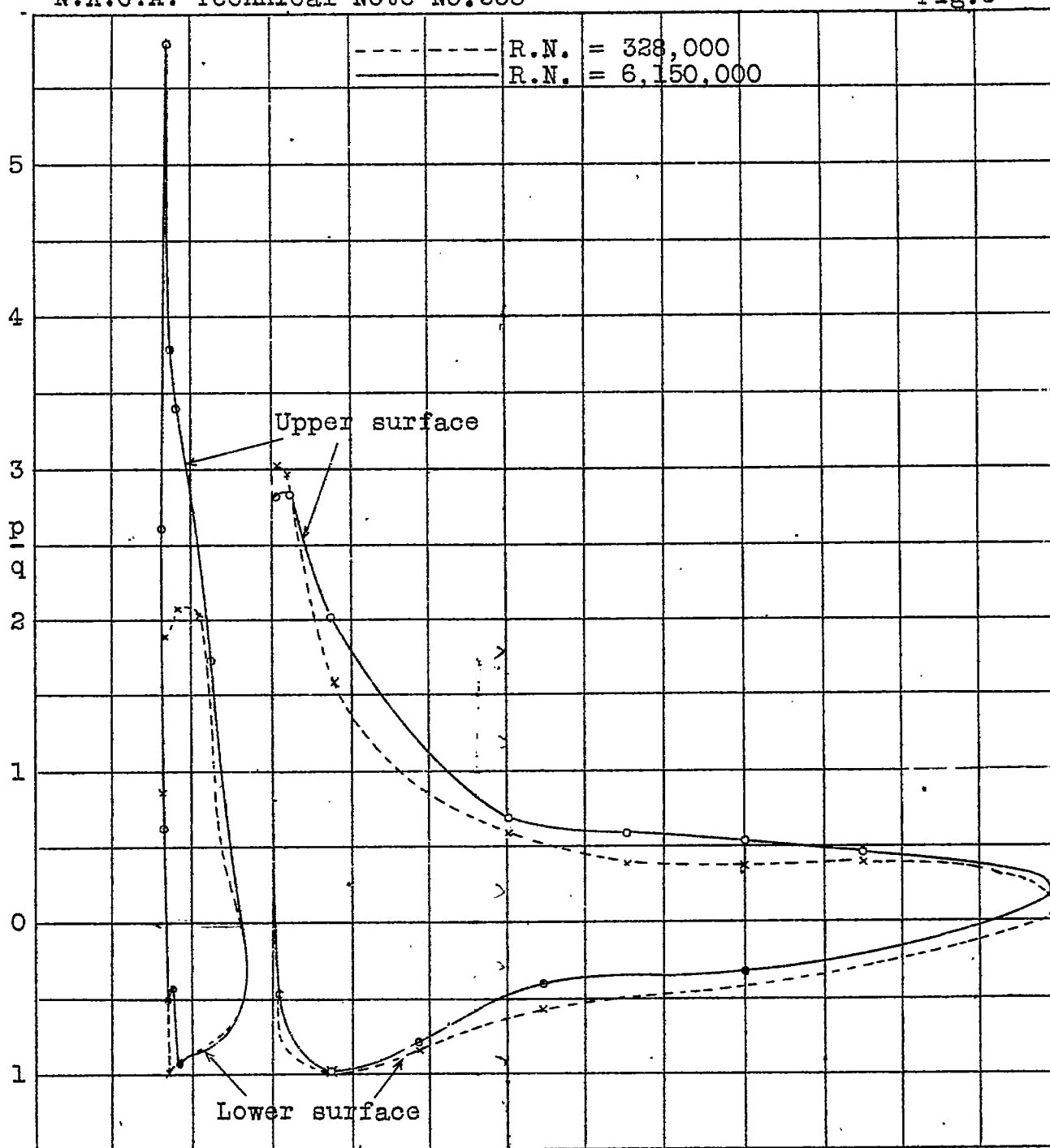


Fig.8 α , angle of attack, $+25^\circ$ 0'
 Pressure distribution diagram. Slotted R.A.F. 31 airfoil.
 Slot fully open.

Fig.9 α , angle of attack, $+31^\circ 0'$

Pressure distribution diagram. Slotted R.A.F. 31 airfoil.
Slot fully open.

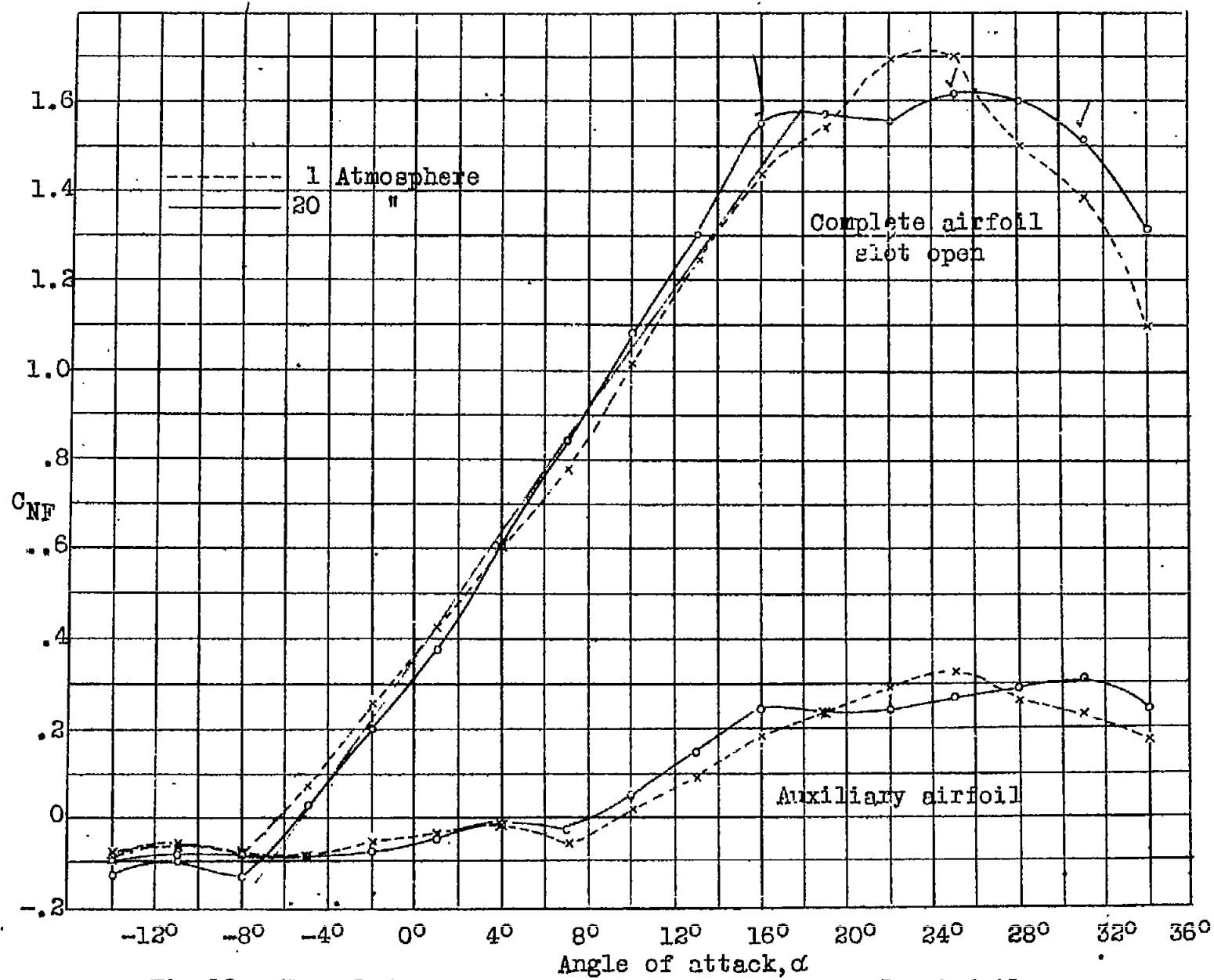


Fig.10 Normal force coefficient. Slotted R.A.F. 31 airfoil.

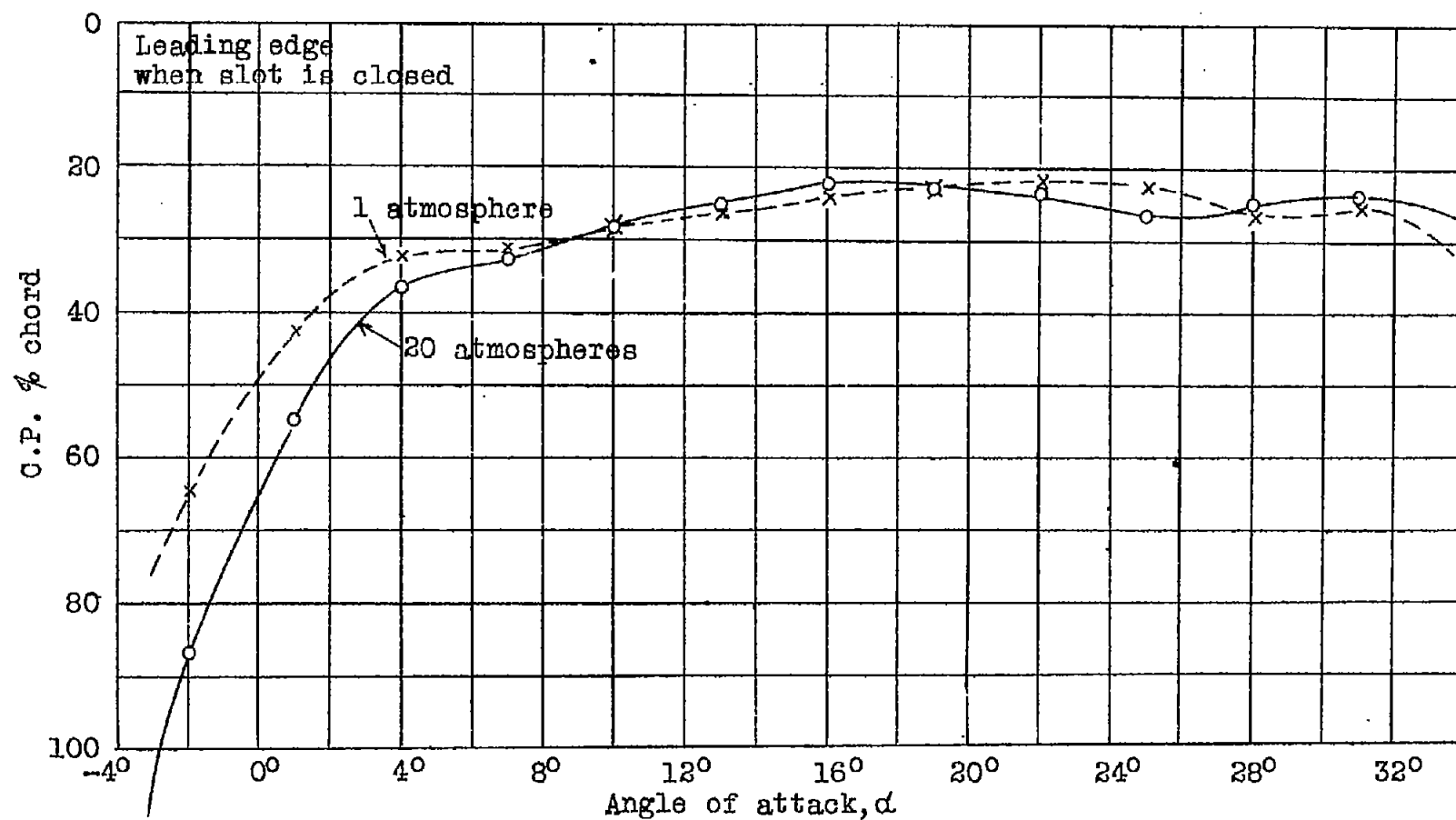


Fig. 11 Center of pressure. Slotted R.A.F. 31 airfoil.

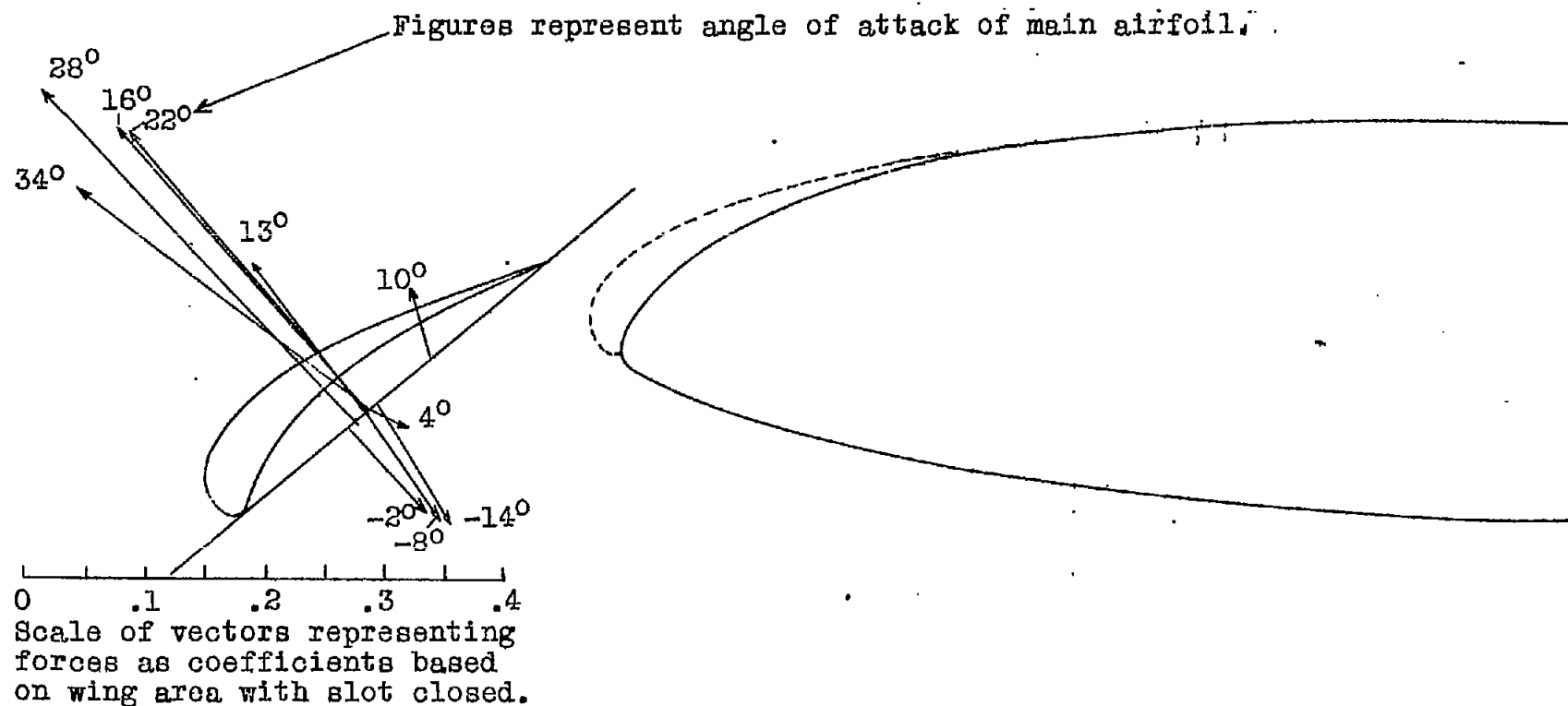


Fig.12 Vector diagram representing forces on auxiliary airfoil with slot fully open. From 20-atmosphere tests.